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Washington, D.C. 20231

Sir:

Transmitted herewith for filing is the patent application of Inventor(s):

Geoffrey Owen Blandy

For: **APPARATUS AND METHOD FOR DETECTING AND HANDLING EXCEPTIONS**

Enclosed are also:

X 36 Pages of Specification including an Abstract
X 5 Pages of Claims
X 8 Sheet(s) of Drawings
X A Declaration and Power of Attorney
X Form PTO 1595 and assignment of the invention to IBM Corporation

CLAIMS AS FILED

FOR	Number Filed		Number Extra		Rate		Basic Fee ($690)
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Docket No. AUS9-2000-0573-US1

APPARATUS AND METHOD FOR DETECTING AND HANDLING EXCEPTIONS

RELATED APPLICATIONS

The present invention is related to commonly assigned and co-pending U.S. Patent Applications _______ (Attorney Docket No. AUS9-2000-0569) entitled "APPARATUS AND METHODS FOR IMPROVED DEVIRTUALIZATION OF METHOD CALLS", _______ (Attorney Docket No. AUS9-2000-0572) entitled "APPARATUS AND METHOD FOR IMPLEMENTING SWITCH INSTRUCTIONS IN AN IA64 ARCHITECTURE", _______ (Attorney Docket No. AUS9-2000-0570) entitled "APPARATUS AND METHOD FOR AVOIDING DEADLOCKS IN A MULTITHREADED ENVIRONMENT", _______ (Attorney Docket No. AUS9-2000-0584) entitled "APPARATUS AND METHOD FOR VIRTUAL REGISTER MANAGEMENT USING PARTIAL DATA FLOW ANALYSIS FOR JUST-IN-TIME COMPILATION", _______ (Attorney Docket No. AUS9-2000-0585) entitled "APPARATUS AND METHOD FOR AN ENHANCED INTEGER DIVIDE IN AN IA64 ARCHITECTURE", _______ (Attorney Docket No. AUS9-2000-0586) entitled "APPARATUS AND METHOD FOR CREATING INSTRUCTION GROUPS FOR EXPLICITLY PARALLEL ARCHITECTURES", and _______ (Attorney Docket No. AUS9-2000-0587) entitled "APPARATUS AND METHOD FOR CREATING INSTRUCTION BUNDLES IN AN EXPLICITLY PARALLEL ARCHITECTURE", filed on even date herewith and hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Technical Field:

The present invention is directed to an apparatus and method for detecting and handling software exceptions such as those thrown in Java and C++. More particularly, the present invention is directed to an apparatus and method for detecting and handling software exceptions in a machine having predication and explicit parallelism.

2. Description of Related Art:

When a software exception is thrown, normal program flow is altered and an exception handler is invoked. Exceptions are typically thrown when an error or other exceptional condition is encountered. This tends to be a rare occurrence for most applications. However, to ensure that thrown exceptions are properly caught it may be necessary to check for their presence frequently. For example, a typical implementation of the Java Virtual Machines will include a check for a pending exception after each method invocation. Furthermore, some applications may use exception throwing as a common flow control device. For these applications, the efficient handling of exceptions is critical to their performance.

Therefore, it would be beneficial to have an apparatus and method of efficiently detecting and handling exceptions. It would further be beneficial to have an apparatus and method for efficiently detecting and

handling exceptions in a machine having predication and explicit parallelism.

SUMMARY OF THE INVENTION

An apparatus and method are provided for detecting and handling exceptions. The apparatus and method make use of predicate registers to identify whether or not an exception is pending. Instructions that are executed only when there is an exception pending are qualified by a first predicate register in the predicate register pair. Instructions that are executed only when there is no exception pending are qualified based on a second predicate register in the predicate register pair.

When an application or system is initialized, the predicate pair is set to indicate that no exception is pending, i.e. the first predicate is set to zero and the second is set to one. When an exception is thrown, the settings of the predicate pair is reversed thereby indicating the presence of a pending exception.

Whenever an exception must be detected, a branch instruction qualified by the first of the predicate pair is inserted into the instruction group at the site where detection is required. All instructions in the instruction group that precede the inserted branch are qualified by the second predicate. In this way, the standard instructions of the group will be executed when no exception is pending but only the inserted branch instruction will be executed when an exception is pending.

The target of the inserted branch depends on whether an exception handler is provided to handle exceptions at the detection site. If not the branch will target code that terminates the current method and

returns to the method's caller. Otherwise the branch will target code that will invoke a lookup handler routine passing it parameters that identify the detection site. The lookup handler routine will determine if any of the exception handler(s) associated with the detection site handles the current pending exception. If so control will be passed to the handler. If not the current method will be terminated and a return will be made to its caller. Other features and advantages of the present invention will be described in, or will become apparent to those of ordinary skill in the art in view of, the following detailed description of the preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an exemplary block diagram of a distributed data processing system according to the present invention;

Figure 2A is an exemplary block diagram of a data processing system according to the present invention;

Figure 2B is an exemplary block diagram of a data processing system according to the present invention;

Figure 3A is a block diagram illustrates the relationship of software components operating within a computer system that may implement the present invention;

Figure 3B is an exemplary block diagram of a Java Virtual Machine (JVM) according to the present invention;

Figure 4 is an exemplary block diagram illustrating a method block in accordance with the present invention;

Figure 5 is an exemplary block diagram illustrating a Just-In-Time (JIT) code buffer;

Figure 6 is a flowchart outlining an exemplary operation of the present invention; and

Figure 7 is a flowchart outlining an exemplary operation of a lookup handler.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference now to the figures, and in particular with reference to **Figure 1**, a pictorial representation of a distributed data processing system in which the present invention may be implemented is depicted. Distributed data processing system **100** is a network of computers in which the present invention may be implemented. Distributed data processing system **100** contains a network **102**, which is the medium used to provide communications links between various devices and computers connected together within distributed data processing system **100**. Network **102** may include permanent connections, such as wire or fiber optic cables, or temporary connections made through telephone connections.

In the depicted example, a server **104** is connected to network **102** along with storage unit **106**. In addition, clients **108**, **110**, and **112** also are connected to a network **102**. These clients **108**, **110**, and **112** may be, for example, personal computers or network computers. For purposes of this application, a network computer is any computer, coupled to a network, which receives a program or other application from another computer coupled to the network. In the depicted example, server **104** provides data, such as boot files, operating system images, and applications to clients **108-112**. Clients **108**, **110**, and **112** are clients to server **104**. Distributed data processing system **100** may include additional servers, clients, and other devices not shown. In the depicted example, distributed data processing system **100** is the Internet with network **102** representing a worldwide

collection of networks and gateways that use the TCP/IP suite of protocols to communicate with one another. At the heart of the Internet is a backbone of high-speed data communication lines between major nodes or host computers, consisting of thousands of commercial, government, educational, and other computer systems, that route data and messages. Of course, distributed data processing system **100** also may be implemented as a number of different types of networks, such as, for example, an Intranet or a local area network.

Figure 1 is intended as an example, and not as an architectural limitation for the processes of the present invention. The present invention may be implemented in the depicted distributed data processing system or modifications thereof as will be readily apparent to those of ordinary skill in the art.

With reference now to **Figure 2A**, a block diagram of a data processing system which may be implemented as a server, such as server **104** in **Figure 1**, is depicted in accordance to the present invention. Data processing system **200** may be a symmetric multiprocessor (SMP) system including a plurality of processors **202** and **204** connected to system bus **206**. Alternatively, a single processor system may be employed. Also connected to system bus **206** is memory controller/cache **208**, which provides an interface to local memory **209**. I/O Bus Bridge **210** is connected to system bus **206** and provides an interface to I/O bus **212**. Memory controller/cache **208** and I/O Bus Bridge **210** may be integrated as depicted.

Peripheral component interconnect (PCI) bus bridge **214** connected to I/O bus **212** provides an interface to PCI local bus **216**. A modem **218** may be connected to PCI local

bus **216**. Typical PCI bus implementations will support four PCI expansion slots or add-in connectors. Communications links to network computers **108-112** in **Figure 1** may be provided through modem **218** and network adapter **220** connected to PCI local bus **216** through add-in boards.

Additional PCI bus bridges **222** and **224** provide interfaces for additional PCI buses **226** and **228**, from which additional modems or network adapters may be supported. In this manner, server **200** allows connections to multiple network computers. A memory mapped graphics adapter **230** and hard disk **232** may also be connected to I/O bus **212** as depicted, either directly or indirectly.

Those of ordinary skill in the art will appreciate that the hardware depicted in **Figure 2A** may vary. For example, other peripheral devices, such as optical disk drive and the like also may be used in addition or in place of the hardware depicted. The depicted example is not meant to imply architectural limitations with respect to the present invention.

The data processing system depicted in **Figure 2A** may be, for example, an IBM RISC/System 6000 system, a product of International Business Machines Corporation in Armonk, New York, running the Advanced Interactive Executive (AIX) operating system.

With reference now to **Figure 2B**, a block diagram of a data processing system in which the present invention may be implemented is illustrated. Data processing system **250** is an example of a client computer. Data processing system **250** employs a peripheral component interconnect (PCI) local bus architecture. Although the depicted example employs a PCI bus, other bus

architectures such as Micro Channel and ISA may be used. Processor **252** and main memory **254** are connected to PCI local bus **256** through PCI Bridge **258**. PCI Bridge **258** also may include an integrated memory controller and cache memory for processor **252**. Additional connections to PCI local bus **256** may be made through direct component interconnection or through add-in boards. In the depicted example, local area network (LAN) adapter **260**, SCSI host bus adapter **262**, and expansion bus interface **264** are connected to PCI local bus **256** by direct component connection. In contrast, audio adapter **266**, graphics adapter **268**, and audio/video adapter (A/V) **269** are connected to PCI local bus **266** by add-in boards inserted into expansion slots. Expansion bus interface **264** provides a connection for a keyboard and mouse adapter **270**, modem **272**, and additional memory **274**. SCSI host bus adapter **262** provides a connection for hard disk drive **276**, tape drive **278**, and CD-ROM **280** in the depicted example. Typical PCI local bus implementations will support three or four PCI expansion slots or add-in connectors.

An operating system runs on processor **252** and is used to coordinate and provide control of various components within data processing system **250** in **Figure 2B**. The operating system may be a commercially available operating system such as OS/2, which is available from International Business Machines Corporation.

An object oriented programming system such as Java may run in conjunction with the operating system and may provide calls to the operating system from Java programs or applications executing on data processing system **250**.

Instructions for the operating system, the object oriented operating system, and applications or programs are located on storage devices, such as hard disk drive **276** and may be loaded into main memory **254** for execution by processor **252.** Hard disk drives are often absent and memory is constrained when data processing system **250** is used as a network client.

Those of ordinary skill in the art will appreciate that the hardware in **Figure 2B** may vary depending on the implementation. For example, other peripheral devices, such as optical disk drives and the like may be used in addition to or in place of the hardware depicted in **Figure 2B**. The depicted example is not meant to imply architectural limitations with respect to the present invention. For example, the processes of the present invention may be applied to a multiprocessor data processing system.

The present invention provides an apparatus and method for detecting and handling exceptions in a machine having predication and explicit parallelism. Although the present invention may operate on a variety of computer platforms and operating systems, it may also operate within a Java runtime environment. Hence, the present invention may operate in conjunction with a Java virtual machine (JVM) yet within the boundaries of a JVM as defined by Java standard specifications. In order to provide a context for the present invention, portions of the operation of a JVM according to Java specifications are herein described.

With reference now to **Figure 3A**, a block diagram illustrates the relationship of software components operating within a computer system that may implement the

present invention. Java-based system **300** contains platform specific operating system **302** that provides hardware and system support to software executing on a specific hardware platform. JVM **304** is one software application that may execute in conjunction with the operating system. JVM **304** provides a Java run-time environment with the ability to execute Java application or applet **306**, which is a program, servlet, or software component written in the Java programming language. The computer system in which JVM **304** operates may be similar to data processing system **200** or computer **100** described above. However, JVM **304** may be implemented in dedicated hardware on a so-called Java chip, Java-on-silicon, or Java processor with an embedded picoJava core. At the center of a Java run-time environment is the JVM, which supports all aspects of Java's environment, including its architecture, security features, mobility across networks, and platform independence.

The JVM is a virtual computer, i.e. a computer that is specified abstractly. The specification defines certain features that every JVM must implement, with some range of design choices that may depend upon the platform on which the JVM is designed to execute. For example, all JVMs must execute Java bytecodes and may use a range of techniques to execute the instructions represented by the bytecodes. A JVM may be implemented completely in software or somewhat in hardware. This flexibility allows different JVMs to be designed for mainframe computers and PDAs.

The JVM is the name of a virtual computer component that actually executes Java programs. Java programs are not run directly by the central processor but instead by

the JVM, which is itself a piece of software running on the processor. The JVM allows Java programs to be executed on a different platform as opposed to only the one platform for which the code was compiled. Java programs are compiled for the JVM. In this manner, Java is able to support applications for many types of data processing systems, which may contain a variety of central processing units and operating systems architectures. To enable a Java application to execute on different types of data processing systems, a compiler typically generates an architecture-neutral file format - the compiled code is executable on many processors, given the presence of the Java run-time system.

The Java compiler generates bytecode instructions that are nonspecific to a particular computer architecture. A bytecode is a machine independent code generated by the Java compiler and executed by a Java interpreter. A Java interpreter is part of the JVM that alternately decodes and interprets a bytecode or bytecodes. These bytecode instructions are designed to be easy to interpret on any computer and easily translated on the fly into native machine code.

A JVM must load class files and execute the bytecodes within them. The JVM contains a class loader, which loads class files from an application and the class files from the Java application programming interfaces (APIs) which are needed by the application. The execution engine that executes the bytecodes may vary across platforms and implementations.

One type of software-based execution engine is a Just-In-Time (JIT) compiler. With this type of execution, the bytecodes of a method are compiled to native machine code upon successful fulfillment of some

type of criteria for "jitting" a method. The native machine code for the method is then cached and reused upon the next invocation of the method. The execution engine may also be implemented in hardware and embedded on a chip so that the Java bytecodes are executed natively. JVMs may interpret bytecodes or use other techniques, such as Just-In-Time compiling, to execute bytecodes. It is not uncommon for a JVM to interpret some methods and Just-In-Time compile others.

When an application is executed on a JVM that is implemented in software on a platform-specific operating system, a Java application may interact with the host operating system by invoking native methods. A Java method is written in the Java language, compiled to bytecodes, and stored in class files. A native method is written in some other language and compiled to the native machine code of a particular processor. Native methods are stored in a dynamically linked library whose exact form is platform specific.

With reference now to **Figure 3B**, a block diagram of a JVM is depicted in accordance with a preferred embodiment of the present invention. JVM **350** includes a class loader subsystem **352**, which is a mechanism for loading types, such as classes and interfaces, given fully qualified names. JVM **350** also contains runtime data areas **354**, execution engine **356**, native method interface **358**, and memory management **374**. Execution engine **356** is a mechanism for executing instructions contained in the methods of classes loaded by class loader subsystem **352**. Execution engine **356** may be, for example, Java interpreter **362** or just-in-time compiler **360**. Native method interface **358** allows access to

resources in the underlying operating system. Native method interface **358** may be, for example, a Java native interface.

Runtime data areas **354** contain native method stacks **364**, Java frames **366**, PC registers **368**, method area **370**, and heap **372**. These different data areas represent the organization of memory needed by JVM **350** to execute a program.

Java frames **366** are used to store the state of Java method invocations. When a new thread is launched, the JVM creates a new Java stack from which the thread will allocate Java Frames. A thread is a part of a program, i.e. a transaction or message, that can execute independently of other parts. In a multithreaded environment, multiple streams of execution may take place concurrently within the same program, each stream processing a different transaction or message.

A Java frame contains all the information pertaining to a single method invocation and is commonly partitioned into three regions. The first region holds all local variables including the input parameters. The second region is typically fixed in size and contains various pointers used by the interpreter including a pointer to the previous frame. The third region is the Java operand stack which is a FIFO stack that holds operands and results of bytecode operations. The operand stack is also used to pass parameters during invocation. The JVM performs only two operations directly on Java operand stacks: it pushes and pops stack items. These items may be object references or primitives such as integers or floating point values.

When the interpreter **362** invokes a Java method, the

interpreter **362** saves the return PC, i.e. a bytecode pointer, in the current frame and makes an indirect call via a JVM invoker field in a method block of the Java method, as described in greater detail hereafter. Upon return from the JVM invoker, the interpreter fetches the current frame and resumes execution starting with the bytecode specified in the returnPC field. When an interpreted method completes, the current frame is discarded and the previous frame is made current.

PC registers **368** are used to indicate the next instruction to be executed. Each instantiated thread gets its own pc register (program counter) and Java stack. If the thread is executing a JVM method, the value of the pc register indicates the next instruction to execute. If the thread is executing a native method, then the contents of the pc register are undefined.

Native method stacks **364** store the state of invocations of native methods. The state of native method invocations is stored in an implementation-dependent way in native method stacks, registers, or other implementation-dependent memory areas. In some JVM implementations, native method stacks **364** and Java frames **366** are combined.

Method area **370** contains class data while heap **372** contains all instantiated objects. The JVM specification strictly defines data types and operations. Most JVMs choose to have one method area and one heap, each of which are shared by all threads running inside the JVM. When the JVM loads a class file, it parses information about a type from the binary data contained in the class file. It places this type information into the method area. Each time a class instance or array is created,

the memory for the new object is allocated from heap **372**. JVM **350** includes an instruction that allocates memory space within the memory for heap **372** but includes no instruction for freeing that space within the memory.

Memory management **374** in the depicted example manages memory space within the memory allocated to heap **370**. Memory management **374** may include a garbage collector which automatically reclaims memory used by objects that are no longer referenced. Additionally, a garbage collector also may move objects to reduce heap fragmentation.

The present invention is equally applicable to either a platform specific environment, i.e. a traditional computer application environment loading modules or native methods, or a platform independent environment, such as an interpretive environment, e.g., a Java environment loading classes, methods and the like. For purposes of explanation of the features and advantages of the present invention, examples of the operation of the present invention will assume a Java environment.

The present invention provides a mechanism by which exceptions in a machine having predication and explicit parallelism are detected and handled. In particular, the present invention may operate in a non-Mixed-Mode-Interpretation (non-MMI) Just-In-Time (JIT) compiler running in a Java Virtual Machine (JVM) on an IA64 platform. MMI describes an environment where methods are initially interpreted until they pass some threshold, such as a frequency of invocation or time consumed, at which time they are compiled. In a non-MMI environment, all methods are compiled. It should be appreciated,

however, that the present invention is not limited to a non-MMI environment and may be implemented in MMI environments without departing from the spirit and scope of the present invention.

The IA64 platform is described in the Intel IA-64 Architecture Software Developer's Manual, available for download at http://developer.intel.com/design/ia-64/downloads/24531702s.htm, which is hereby incorporated by reference in its entirety. Briefly, IA64 allows a compiler or programmer to explicitly group instructions to be executed concurrently. IA64 also provides a set of 64 single bit predicate registers which can be used to control instruction execution. A predicated register can be associated with an instruction as a "qualifying predicate." When the qualifying predicate is true, the instruction executes normally. When the qualifying predicate is false, the instruction will not modify architectural state thereby acting essentially as a no-operation (a NOP).

With the present invention, a pair of predicate registers P1 and P2 is utilized to determine if an exception is pending or not. In the case of the present invention, P1 is true when an exception is pending and is false otherwise. P2 is true when no exception is pending and false otherwise. The values of predicate registers are set by the results of instructions, such as compare (cmp) and test bit (tbit).

The present invention provides methods for using these predicate registers to detect and handle exceptions. In particular, the present invention provides a method for initializing the predicate register pair when crossing a boundary from non-JITted code to JITted code, a method for setting the predicate pair to

indicate the presence of a pending exception, a method for running exception detecting instructions concurrently with instructions that are only allowed to complete if no exception is present, and a method to pass control to the appropriate exception handler when an exception occurs.

As mentioned above, the present invention includes a method for initializing a predicate register pair for use in exception detection and handling when crossing a boundary from non-JITted code to JITted code. With the method of the present invention, when invoking a JITted method from non-JITted code, e.g., a native method or the JVM itself, a "glue" routine is used to set up the required environment, such as setting up input registers and various flags. A "glue" routine is a routine that is used to perform some conversion, translation or other process that makes one system work with another. In this case, the glue routine operates to allow a Java Virtual Machine and a Just-In-Time compiler to work together.

The glue routine of the present invention also sets the predicate register pair by examining an exception flag maintained by the JVM. If the exception flag in the JVM indicates that an exception occurred, the predicate registers are set to indicate an exception. In other words, P1 is set to true and P2 is set to false.

In addition, when returning to JITted code from non-JITted code, e.g., returning from a call into the JVM, small "glue" routines are executed to restore the state required by the JITted environment. If the call could have caused an exception to be thrown, the predicate register pair is set again, via examination of the exception flag, before returning to JITted code. When JITted code throws an exception, a routine is called

which sets up storage locations to indicate the pending exception and additionally sets the predicate register pair to indicate the presence of the exception, i.e. P1 is set to true and P2 is set to false.

When the JIT compiler generates instructions following a method invocation, it is free to combine, in a single instruction group, instructions that must only execute in the presence of an exception with those which must only execute in the absence of an exception. Those instructions that must execute only when no exception is pending are qualified by predicate register P2 while the instructions that must execute when an exception is pending are qualified by predicate register P1. By "qualified" what is meant is that the predicate register is a qualifying predicate, i.e. the predicate register is one whose value determines whether the processor commits the results computed by the instruction.

In a preferred embodiment, only a single branch instruction is used to handle the exception so that the code might appear as:

```
(P2) ld   r14=[r35]
(P2) mov  r37=r8
(P2) adds r9=8, r8
(P1) br.cond.spnt   handleException
```

For each method that handles exceptions, an exception table indicates all try and catch blocks. Each entry of the table identifies a range of bytecodes that represents the try phrase and a bytecode offset that represents the start of the exception handler. Each entry also includes an identification of what type of exception is handled and provides an auxiliary pointer field available for JIT compiler use. This auxiliary pointer field, in the present invention, is used to point to the compiled code

representing the exception handler. For example, an entry in an exception table may take the form of:

```
StartPC  EndPC  HandlerPC  ExceptionType wordForJit
```

If an invoke is not in a try range, the JIT compiler will generate the predicate register P1 qualified branch to go to an appropriate return stub. The collection of return stubs is placed so that they can be reached by a relative branch from any JITted method and are replicated if required.

Figure 4 is an exemplary block diagram of a method block in accordance with the present invention. The method block **400** is a control block data structure used to represent control parameters of a Java method. The method block **400** has a number of fields including fields **410** for storing the address of return stubs for the method associated with the method block. The return stubs are pieces of code that perform a type of return to an invoking, or calling, routine. Such returns may include, for example, standard returns, synchronized returns, returns for saving floating point registers, and the like, as is generally known in the art. An example of a standard return stub may be:

```
mov  ar.pfs = r35
mov  rp = r36
br.ret  rp
```

An example of a synchronized return stub may be:

```
mov  ar.pfs = r35
mov  rp = r36
br.cond  MonitorExit
```

When a method is JITted, the results of the JIT

compiler are stored in a JIT code buffer for use. **Figure 5** is an exemplary block diagram illustrating a JIT code buffer in accordance with the present invention. As shown in **Figure 5**, the JIT code buffer **500** stores the return stubs for the methods, the lookup handler and compiled methods. The JIT code buffer **500** may be of various sizes but is typically 16 MB in size. Of these 16 MB, less than 4k is used to store the returns stubs and lookup handler. The remainder of the JIT code buffer **500** is used to store the compiled methods.

The compiled JITted methods may make use of the return stubs stored in the JIT code buffer **500** during exception handling. Exception handling is performed using the lookup handler which either invokes the compiled method exception handler or passes control to the return stubs in the JIT code buffer **500**.

The stubs perform whatever return function is required of the method, including monitor release for synchronized methods. The return stubs perform a "pure" return as is required for exception handling. This provides complete freedom to the JIT compiler when creating standard return sequences that will be used for non-exception returns. For example, a standard return could contain conditional storage modifications that would not be allowed when an exception was present.

With the present invention, if an exception is encountered, and the exception is within a try block of the method, the JIT compiler creates a branch to a "snippet," which is code generated specifically for that method. The snippet identifies a known register with the bytecode offset of an invoke that branches to a lookup handler. An example snippet is:

```
mov  r8 = pc
movl r9 = currentMethodBlock
br.cond   LookupHandler
```

The lookup handler searches the method's exception table to see if the bytecode offset is within the range of a try block which handles the current instruction. If it is, the predicates are reset to indicate no pending exception and control is passed to the compiled exception handler for the method. Otherwise, a branch is made to the return stub appropriate for this method with the predicate registers indicating a pending exception.

In this way, methods that do not handle the current exception return to the calling routine with P1=true and P2=false. The post invoke code for that call is executed and the appropriate return stub or snippet is invoked until the exception is handled. If the exception is not handled by any method in the call chain, the JVM terminates the thread and prints a stack trace identifying the exception.

Figure 6 is a flowchart outlining an exemplary operation of the present invention. As shown in **Figure 6**, the operation starts with an invoke instruction for invoking a method being generated by the compiler (step **610**). A determination is made as to whether there are instructions before the exception branch (step **620**).

If there are instructions before the exception branch, the predicate register P2 predicated instructions are generated (step **630**). Thereafter, or if there are no instructions before the exception branch, a determination is made as to whether or not the instruction is in a try block, or range, of the method (step **640**). If not, the predicate register P1 predicated instructions to branch

to a return stub for the method is generated (step **650**). If the instruction is in a try block, the predicate register P1 predicated instruction to branch to a snippet associated with the method is generated (step **660**). The snippet is then generated (step **670**).

Figure 7 is a flowchart outlining an exemplary operation of the lookup handler of the present invention. As shown in **Figure 7**, the operation involves determining if the pc, i.e. bytecode pointer, for a current exception is within a try block (step **710**). This operation may involve using the exception table for the method to determine if the exception is handled by the method exception handler. If so, the lookup handler invokes the compiled method exception handler (step **720**). If not, the lookup handler invokes an appropriate return stub for the method (step **730**).

Thus, the present invention provides methods for using predicate registers to detect and handle exceptions. In particular, the present invention provides a method for initializing the predicate register pair when crossing a boundary from non-JITted code to JITted code, a method for setting the predicate pair to indicate the presence of a pending exception, a method for running exception detecting instructions concurrently with instructions that are only allowed to complete if no exception is present, and a method to pass control to the appropriate exception handler when an exception occurs.

It is important to note that while the present invention has been described in the context of a fully functioning data processing system, those of ordinary skill in the art will appreciate that the processes of the present invention are capable of being distributed in

the form of a computer readable medium of instructions and a variety of forms and that the present invention applies equally regardless of the particular type of signal bearing media actually used to carry out the distribution. Examples of computer readable media include recordable-type media such a floppy disc, a hard disk drive, a RAM, and CD-ROMs and transmission-type media such as digital and analog communications links.

The description of the present invention has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain the principles of the invention, the practical application, and to enable others of ordinary skill in the art to understand the invention for various embodiments with various modifications as are suited to the particular use contemplated.

CLAIMS:

What is claimed is:

1. A method of handling exceptions in a device having predication, comprising:

determining if an exception is pending based on values of a predicate register pair; and

handling the exception when it is determined that an exception is pending.

2. The method of claim 1, wherein determining if an exception is pending includes determining if a value of a first predicate register is true and a second predicate register is false.

3. The method of claim 1, wherein handling the exception includes determining if an address of an instruction within a method that threw the exception is in a try block, and if the address of the instruction is not in the try block, invoking a return associated with the method.

4. The method of claim 3, wherein if the exception is in the try block, using an associated exception handler for the method.

5. The method of claim 1, wherein the device has an IA64 architecture.

6. The method of claim 1, wherein handling the exception includes determining if the an instruction in a method that threw the exception is in a try block and

invoking a snippet associated with the method.

7. The method of claim 6, wherein the snippet invokes a lookup handler for determining if the exception is within a try block of the method.

8. The method of claim 7, wherein the lookup handler determines if the exception is within the try block of the method by searching an exception table associated with the method and determining if an address of the instruction is within the exception table.

9. An apparatus for handling exceptions in a device having predication, comprising:

means for determining if an exception is pending based on values of a predicate register pair; and

means for handling the exception when it is determined that an exception is pending.

10. The apparatus of claim 9, wherein the means for determining if an exception is pending determines if a value of a first predicate register is true and a second predicate register is false.

11. The apparatus of claim 9, wherein the means for handling the exception determines if an address of an instruction within a method that threw the exception is in a try block, and if the address of the instruction is not in the try block, invokes a return associated with the method.

12. The apparatus of claim 11, wherein if the exception is in the try block, the means for handling uses an

associated exception handler for the method.

13. The apparatus of claim 9, wherein the apparatus has an IA64 architecture.

14. The apparatus of claim 9, wherein the means for handling the exception determines if the an instruction in a method that threw the exception is in a try block and invokes a snippet associated with the method.

15. The apparatus of claim 14, wherein the snippet invokes a lookup handler for determining if the exception is within a try block of the method.

16. The apparatus of claim 15, wherein the lookup handler determines if the exception is within the try block of the method by searching an exception table associated with the method and determining if an address of the instruction is within the exception table.

17. A computer program product in a computer readable medium for handling exceptions in a device having predication, comprising:

first instructions for determining if an exception is pending based on values of a predicate register pair; and

second instructions for handling the exception when it is determined that an exception is pending.

18. The computer program product of claim 17, wherein the first instructions for determining if an exception is pending includes instructions for determining if a value of a first predicate register is true and a second

predicate register is false.

19. The computer program product of claim 17, wherein the second instructions for handling the exception includes instructions for determining if an address of an instruction within a method that threw the exception is in a try block, and instructions for invoking a return associated with the method if the address of the instruction is not in the try block.

20. The computer program product of claim 19, wherein the second instructions further include instructions for using an associated exception handler for the method if the exception is in the try block.

21. The computer program product of claim 17, wherein the device has an IA64 architecture.

22. The computer program product of claim 17, wherein the second instructions for handling the exception includes instructions for determining if the an instruction in a method that threw the exception is in a try block and instructions for invoking a snippet associated with the method.

23. The computer program product of claim 22, wherein the snippet invokes a lookup handler for determining if the exception is within a try block of the method.

24. The computer program product of claim 23, wherein the lookup handler determines if the exception is within the try block of the method by searching an exception table associated with the method and determining if an

address of the instruction is within the exception table.

Docket No. AUS9-2000-0573-US1

ABSTRACT OF THE DISCLOSURE

APPARATUS AND METHOD FOR DETECTING AND HANDLING EXCEPTIONS

An apparatus and method are provided for detecting and handling exceptions. The apparatus and method make use of predicate registers to identify whether or not an exception is pending. Instructions that are executed only when there is an exception pending are qualified by a first predicate register in the predicate register pair. Instructions that are executed only when there is no exception pending are qualified based on a second predicate register in the predicate register pair. When an exception is thrown, a determination is made as to whether or not the instruction that threw the exception is in a try block, or range, of the method that threw the exception. If not, the first predicate register predicated instruction to branch to a return stub for the method is generated. If the instruction that threw the exception is in a try block of the method, the first predicate register predicated instruction to branch to a snippet associated with the method is generated. The calls a lookup handler for the method. The lookup handler determines if the exception is within a try block of the method. If the exception is within a try block, the lookup handler invokes an associated exception handler for the method. If the exception is not within a try block of the method, the lookup handler invokes an appropriate return stub for the method.

EK287384647US

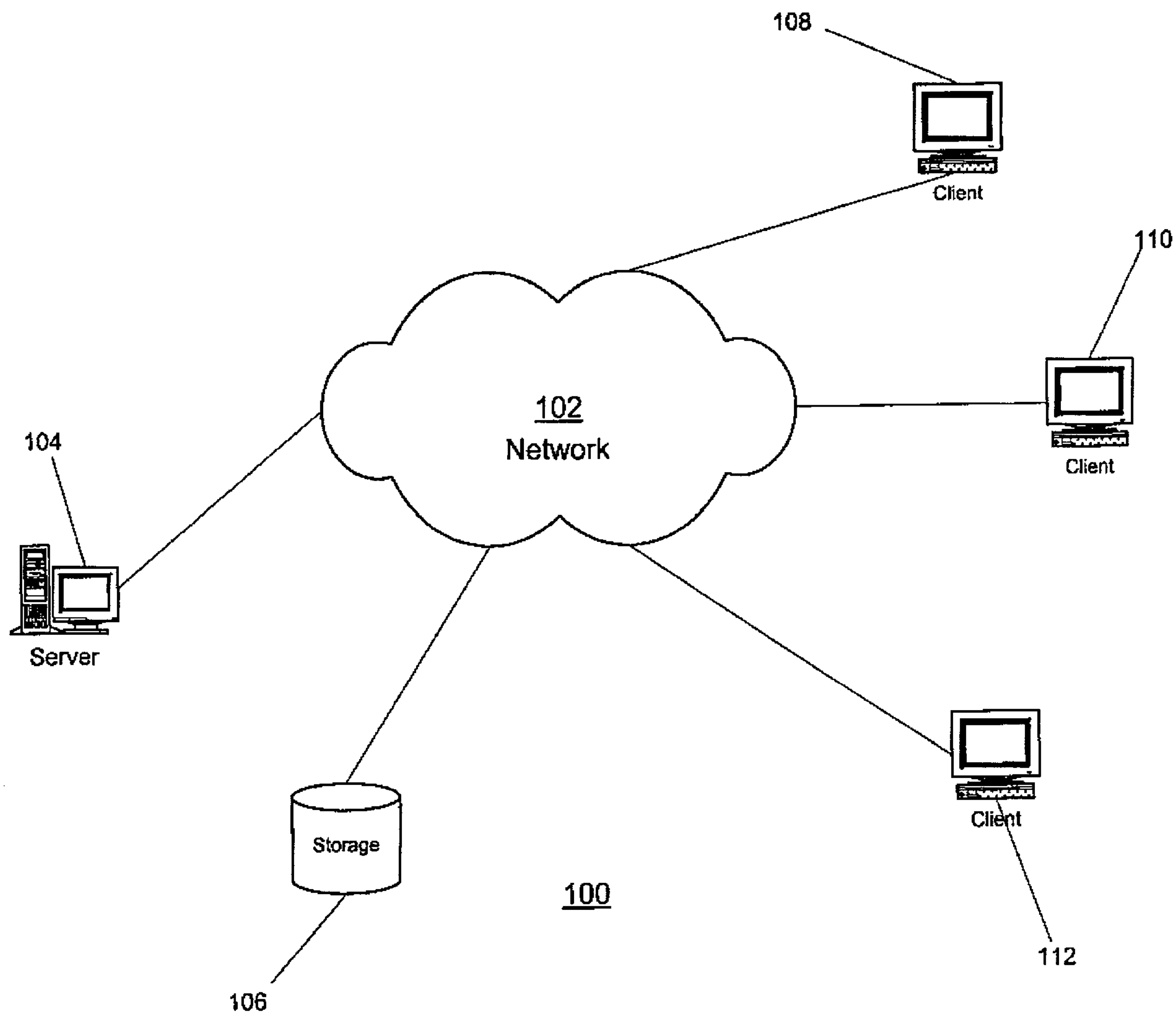


Figure 1
AUS9-2000-0573-US1

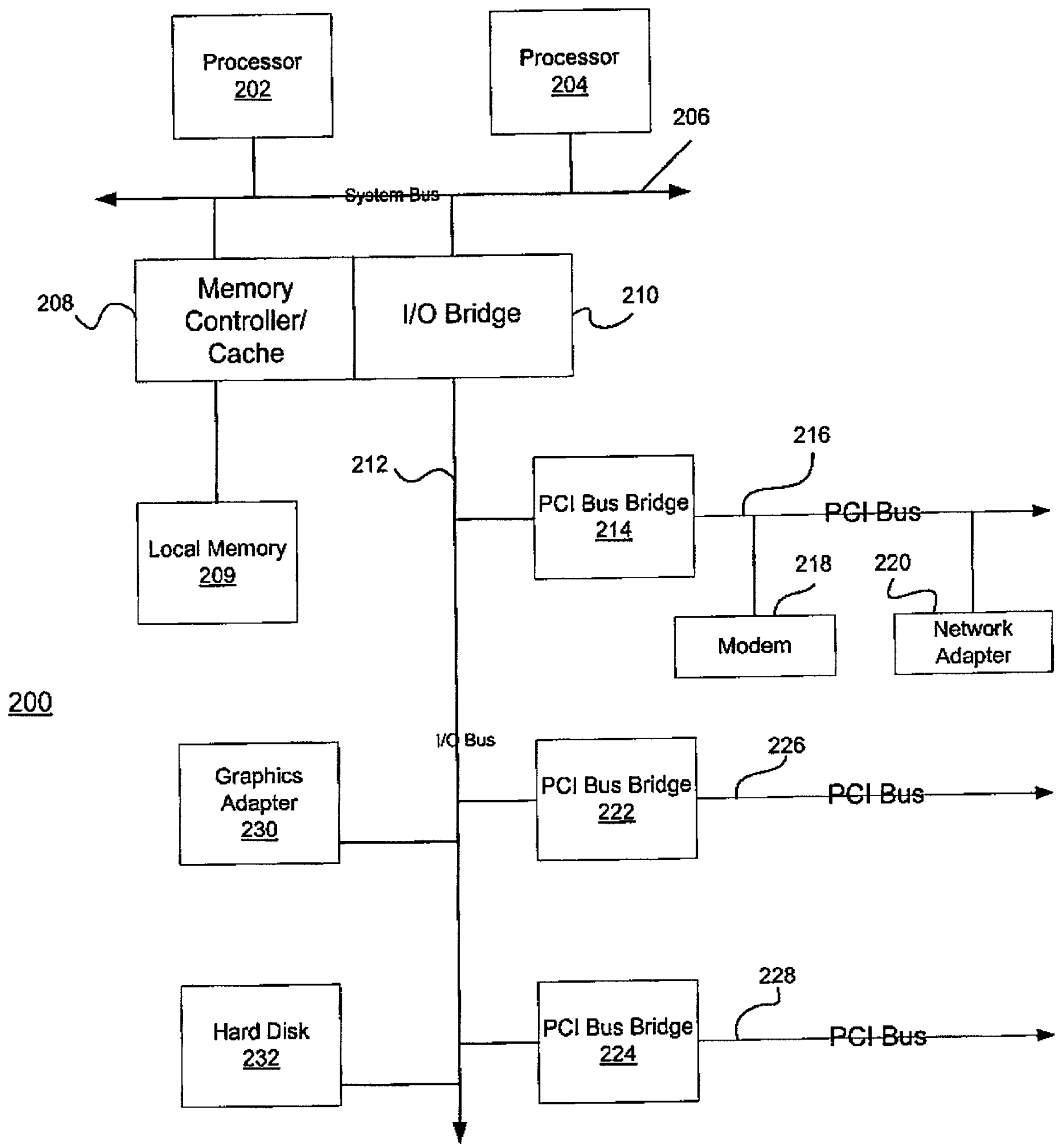


Figure 2A

AUS9-2000-0573-US1

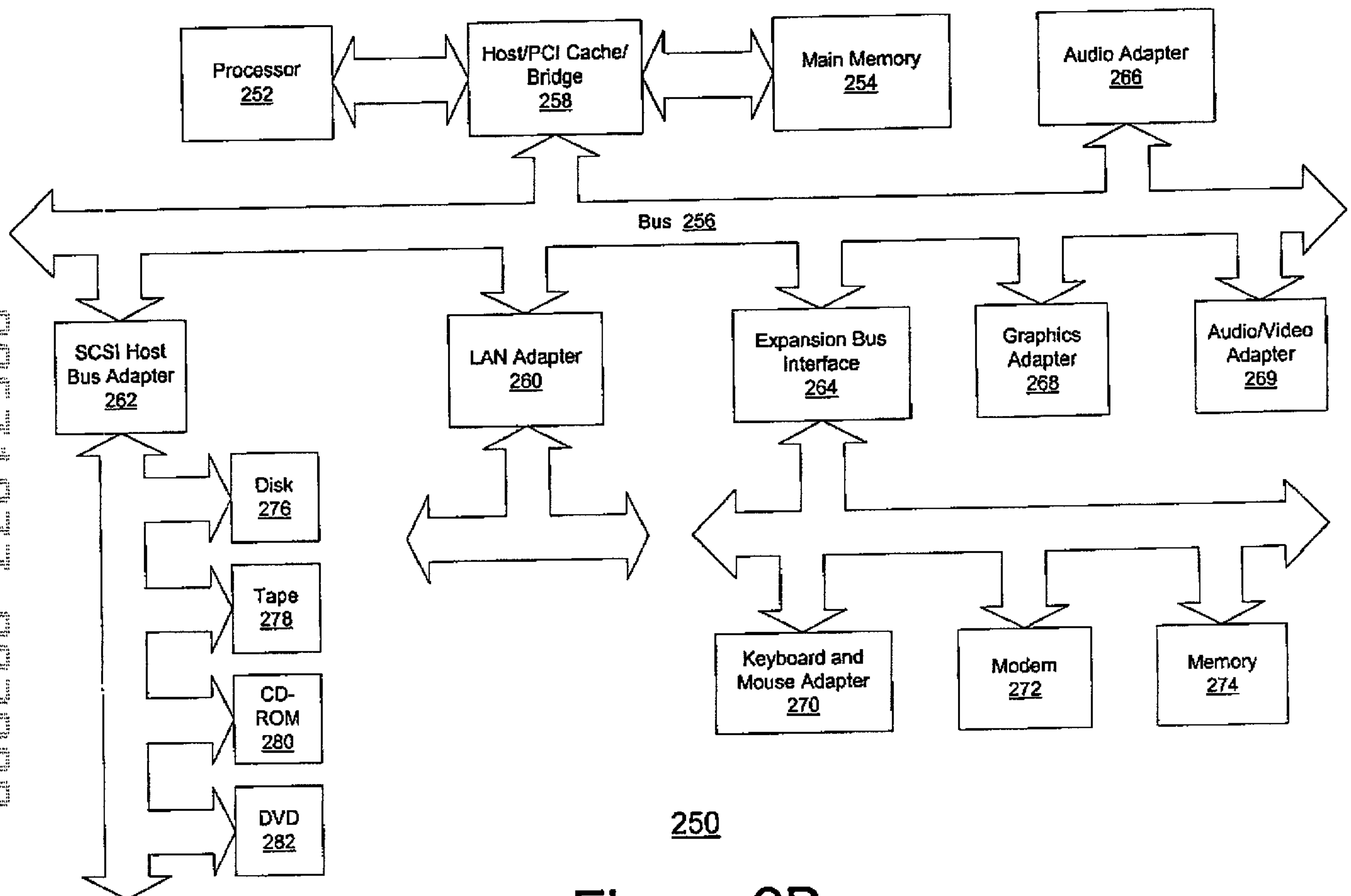
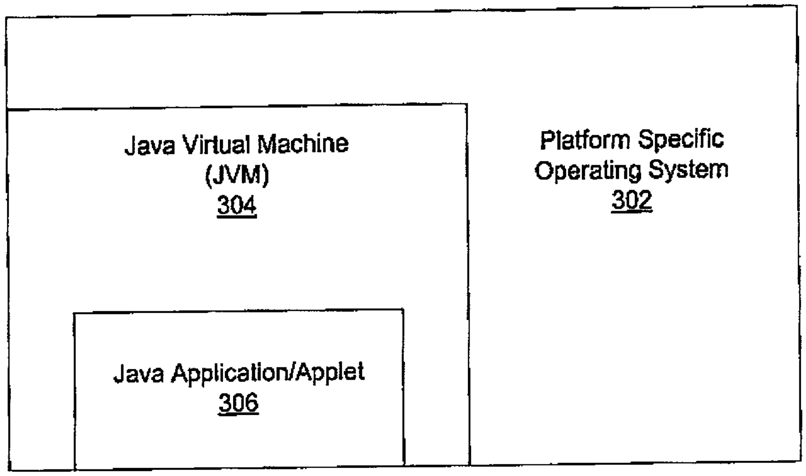


Figure 2B

AUS9-2000-0573-US1



300

Figure 3A

AUS9-2000-0573-US1

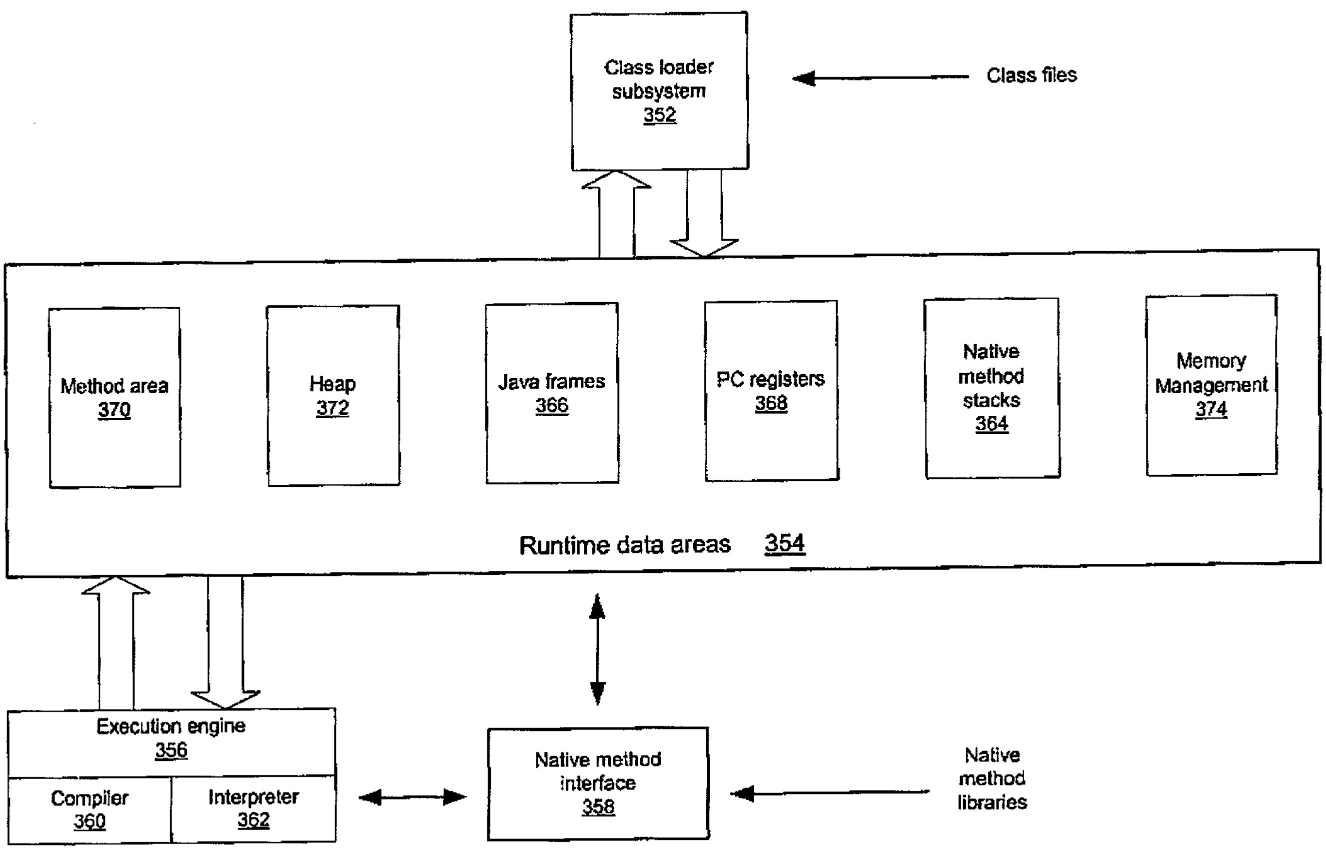


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Figure 3B

AUS9-2000-0573-US1

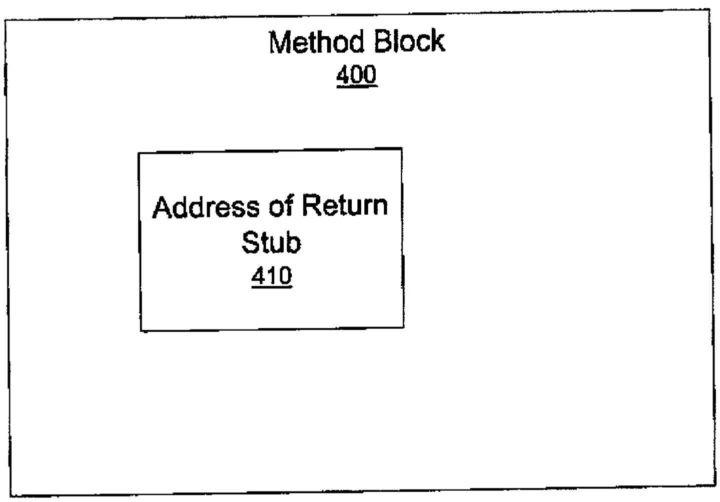

Figure 4

AUS9-2000-0573-US1

JIT Code Buffer
500

Return Stubs

```
e.g.  mov      ar.pfs = r35
      mov      rp     = r36
      br.ret   rp
```

Synchronized Return Stubs

```
e.g.  mov      ar.pfs = r35
      mov      rp     = r36
      br.cond MonitorExit
```

MonitorExit

.

.

.

Lookup Handler

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.

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Compiled Methods

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.

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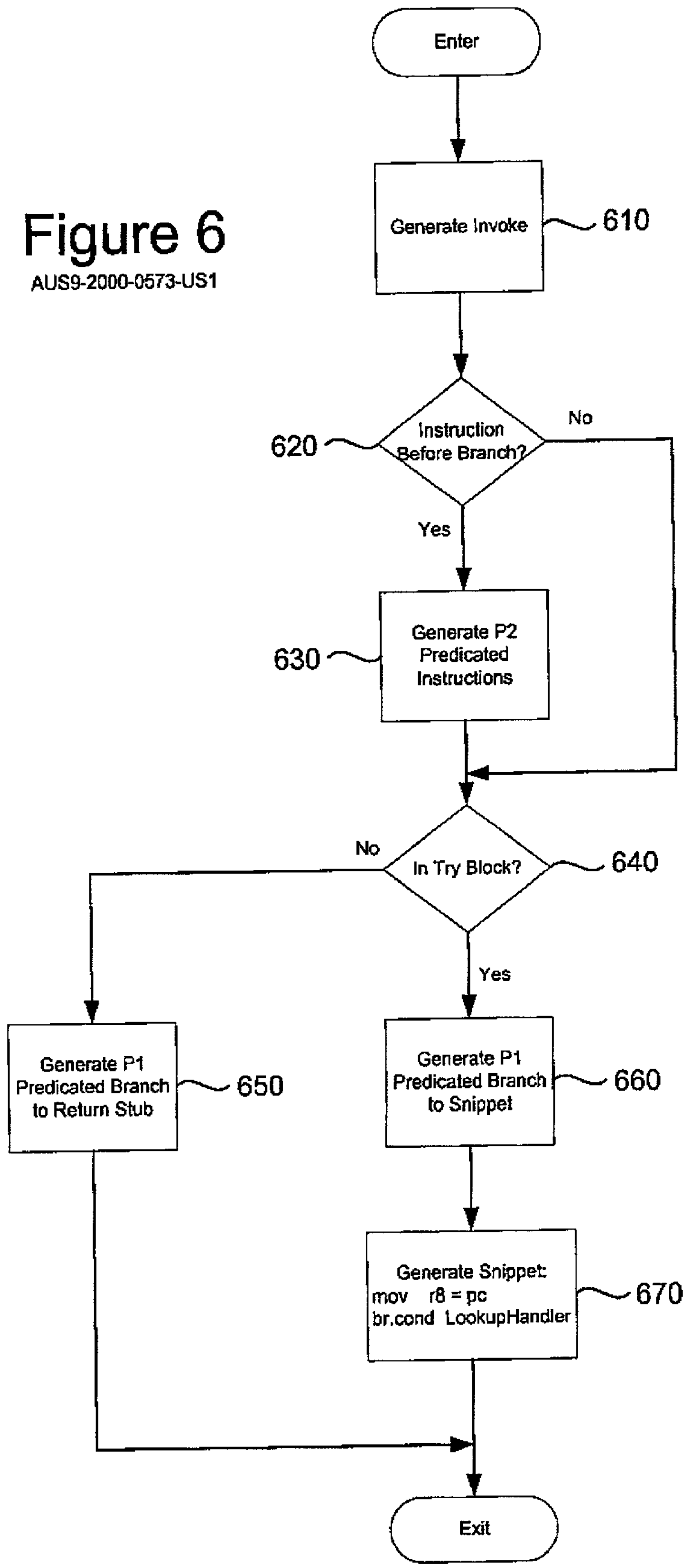
Figure 5

AUS9-2000-0573-US1

Figure 6
AUS9-2000-0573-US1



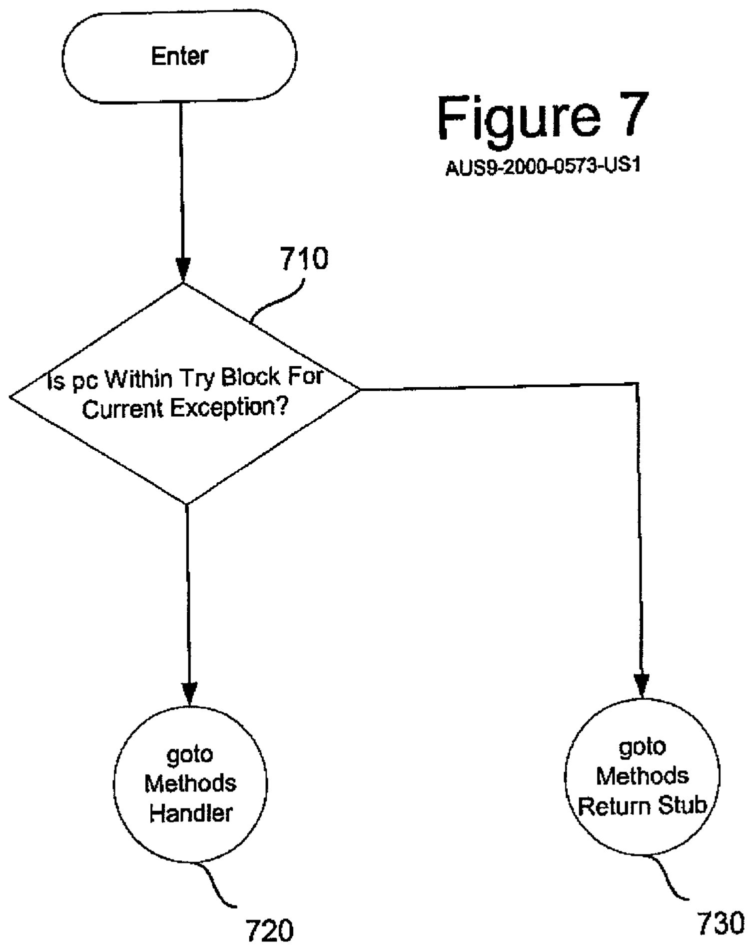


Figure 7

AUS9-2000-0573-US1

DECLARATION AND POWER OF ATTORNEY FOR

PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

<u>APPARATUS AND METHOD FOR DETECTING AND HANDLING EXCEPTIONS</u>

the specification of which (check one)

<u>X</u> is attached hereto.

__ was filed on ____________________
as Application Serial No. ____________________
and was amended on ____________________
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s): Priority Claimed

____________	____________	____________	___ Yes ___ No
(Number)	(Country)	(Day/Month/Year)	

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information material to the patentability of this application as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

____________	____________	____________
(Application Serial #)	(Filing Date)	(Status)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be

true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorneys and/or agents to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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INVENTORS SIGNATURE: ____________ DATE: 9/26/2000

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